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SPARK CAMERA ANNOTATION AND CONTROL SYSTEM FOR THE BRL TRANSONIC RANGE FACILITY

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New cameras were recently installed into the Transonic Range Facility of the Ballistic Research Laboratory as part of a range modification program. An automated annotation and control system was designed and fabricated by the Electronics Team of the Free Flight Aerodynamics Branch, Launch and Flight Division, to interface with the new cameras. This annotation system consists of electronic instrumentation and custom-built circuits installed into the cameras themselves. It provides for remote opening and closing of the shutter on all cameras and for transmitting date, round number, and station identification information to each camera to be photographically impressed upon the film at each station. It also has features for determining a variety of status conditions such as shutter status and film load-unload conditions. This system was completed in December 1986 and was fully operational by the end of January 1987. Details of the design and fabrication of this system are given in this report.

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CONTENTS

LIST OF FIGURES

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1. INTRODUCTION

The Transonic Range Facility (TRF) of the Ballistic Research Laboratory is part of the Launch and Flight Division (LFD). Actual-sized projectiles are fired through the range unrestrained, i.e. not affected by any forces other than what they experience in free flight. Spark photograph stations located throughout the length of the range are used to provide shadowgraph pictures of the test projectile at various stages of its flight.

The range provides a means to study the aerodynamic behavior of projectiles. Specifically, it provides data for determining aerodynamic coefficients, performing dispersion studies, and for studying flow characteristics.

The primary instrument used to gather data in the TRF is the spark photograph camera located at surveyed locations in the range. As the test projectile passes a camera station, a high intensity, short duration spark is triggered, and an image of the projectile and its shadow on a reflecting screen is captured on film. Measurement of the position of the projectile image, relative to survey wire images, provides data for determining velocity versus time or distance, and data on the angular motion of the projectile.

New cameras were recently installed into the range as part of a range modernization program. The older cameras had been installed in the late 1940s, or early 1950s.[1] An automated annotation system was installed in the TRF to interface with the new cameras. This system was completed in December 1986 and was fully operational by the end of January 1987. It is comprised of electronic instrumentation located in the range control room and of custom built circuits that are installed into the cameras. It provides for remote shutter opening and closing on all of the cameras and for sending date, round number, and station identification information to each camera to be photographically impressed upon the film at each station. It also has features for determining a variety of status conditions such as whether the shutters are opened, closed or stuck and whether the film has been loaded. The remainder of this report will briefly describe the TRF as related to the spark photographic cameras and discusses some features of the new camera bodies that were recently installed. The bulk of this report, however, will deal with the Spark camera automated annotation and control system.

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[1] *Rodgers, Jr., Walter K., "The Transonic Free Flight Range," Ballistic Research Laboratories Report 1044, June 1958. AD200177.*

2. TRANSONIC RANGE FACILITY

The TRF was designed in 1944 and construction was completed in 1947.[1] The initial instrumentation was completed for full-scale operation in 1950.

The range itself, Figure 1, is a building nearly 365 m long. The forward section of the building (nearest to the gun ramp) is reinforced concrete. The remainder is a steel frame and sheet metal structure. Only the first 230 meters are instrumented, and the range has a cross section of 7.3 m × 7.3 m. The steel frame portion of the range is insulated, and the instrumented portion of the range has radiant heating.

The primary instrumentation is a system of 25 spark photographic stations spread out through the range. Each spark station consists of two cameras: two high intensity, air-gap spark light sources and two large-beaded projection screens. Each screen is a 3.65 m × 3.65 m square. One of the screens is mounted vertically on the right-hand wall, as looking down range, and the other is mounted horizontally on the ceiling of the range. A camera is mounted on the wall opposite the vertical screen and another is placed in a pit in the floor and is focused onto the ceiling screen. The spark-light sources approximate a point-light source and provide a short duration, high intensity light. They are used to cast a shadow of the test projectile onto the projection screen as the projectile travels past the spark station. A short duration is necessary in order to 'freeze' the motion. At some wall stations there is a second spark source used to cover a variety of trajectory variations that may occur, especially for lower velocity rounds that may experience excessive vertical drop for the end stations.

The camera stations are situated 6 m apart in groups of five. There is 21 m between groups. The distance between the first station and the last station is 204 m. There are fiducial wires strung circumferentially along the inside of the range at each station. These wires are centered in front of the screens and are photographed along with the projectile and projectile shadow. The fiducial wires (as well as the cameras) are accurately surveyed in position and are used to provide a coordinate system for making relative measurements from each station.

Located approximately 2.3 m ahead of each station (relative to the center of the projection screen) are photoelectric triggers. These triggers consist of a light source projected onto a curved reflecting screen mounted on the ceiling of the range. A cylindrical lens is used to provide a fan-shaped beam through which the projectile must pass. Light is reflected from the screen to a photomultiplier tube. A projectile passing through the beam will cause a decrease in the amount of

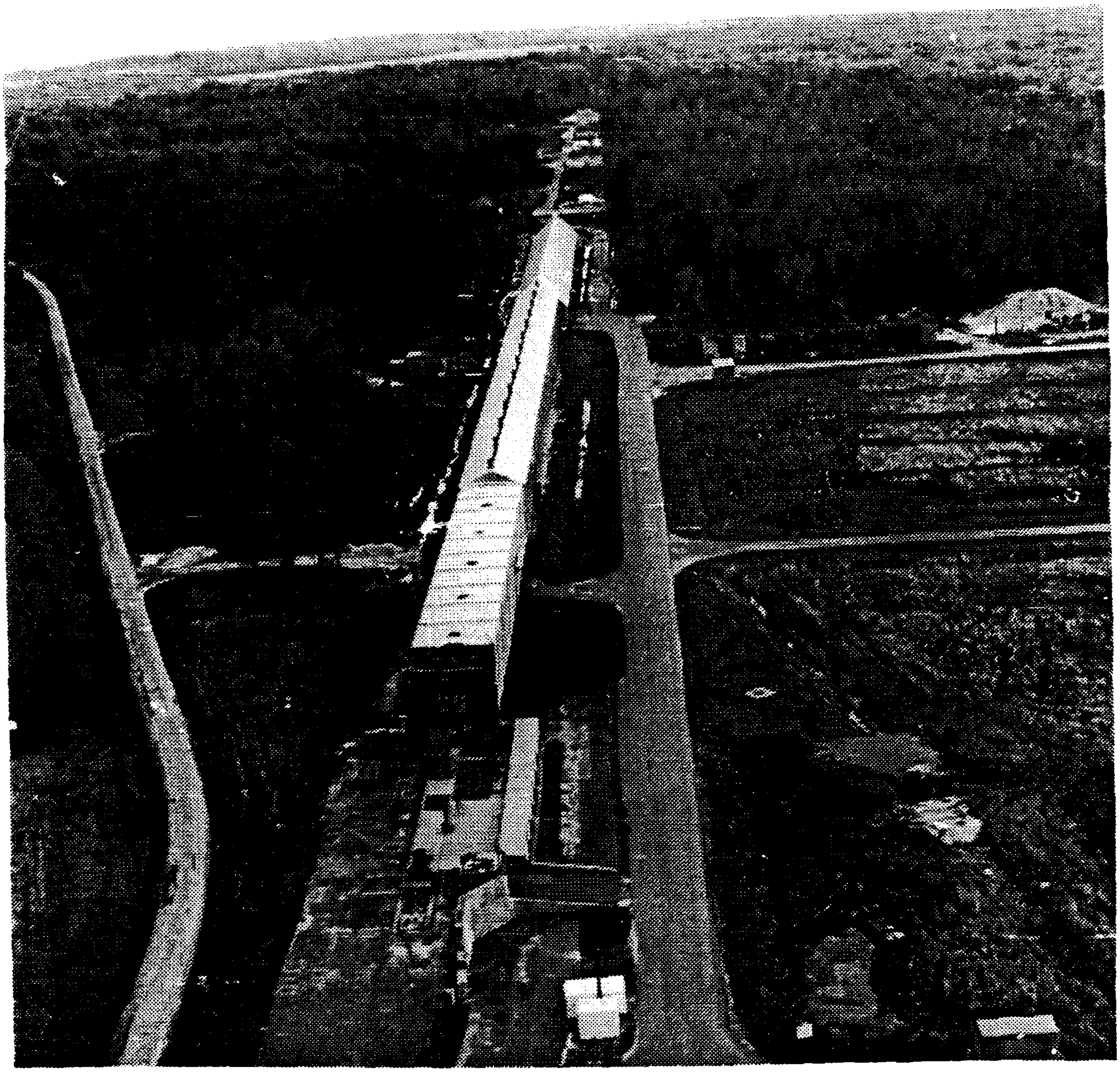


Figure 1. Photograph of transonic range facility (aerial view).

light reaching the photomultiplier tube which produces a voltage pulse that triggers the spark sources, after a suitable delay.

The film from the spark photograph cameras provides a variety of data. Range (or position) versus time and velocity versus time are obtained with the help of a chronograph system that is triggered by the spark sources. Lift information (from center of gravity motion) and yaw angle histories can be extracted as well.

Figure 2 is a photograph of the interior of the Transonic Range. This is a view from the end of the fifth group of cameras, looking up range toward group 1. The horizontal and vertical projection screens are evident. Pit cameras can be seen mounted to the left side of the pit walls. The wall cameras are not visible in the photograph but are mounted on the wall opposite the vertical screens and are accessed via the platform, which is visible on the right side of the photograph.

This completes a brief description of the spark photography system at the TRF. A more complete description of the range and photographic stations is presented in Reference 1. The remainder of this report deals with a new, automated film annotation system. This annotation system was incorporated into new camera bodies recently installed.

3. SPARK PHOTOGRAPHIC CAMERAS

3.1 Original system. The older cameras used lenses designed for aerial surveillance during World War II. These lenses are compounded with coated optical pieces. They are f/2.5, 7-in focal length lens of very high quality. The lenses were threaded into a camera body designed specifically for the transonic range. The camera bodies have standard 4 x 5-in film holders that can accept glass plate film, 4 x 5-in cut, and polaroid film. Floor cameras were bracket-mounted in pits for protection and were focused on the horizontal screens mounted on the range ceiling. Wall cameras were bracket-mounted on the left range wall (looking downrange) and were focused on the vertical screen on the right range wall. By illuminating the reflecting screen and the survey wires with a flood lamp and by screwing the lens in or out of the camera body, focusing was accomplished when a sharp image of the survey wire shadow and survey beads, mounted on the wires, was obtained. Once focused, the lens was locked into place with a locking ring on the inside of the camera. The cameras had a solenoid-operated shutter that covered the lens, but was not an integral part of the cameras shutters.

Figure 2. Photograph of the interior of transonic range.

The film from the cameras was annotated after each firing. Station identification was accomplished by stenciling the reflecting screen with black paint. Each round fired through the range is assigned a number and was manually impressed on each piece of film with a perforation marker. This was usually done after the film was processed. For a single round, this had to be done for each piece of film (total of 50).

3.2 New cameras. The spark photographic cameras were replaced with new camera bodies purchased to BRL specifications in 1983-1984 from the Image Technology Corporation. They were installed by TRF personnel in 1985. Figure 3 is a photograph of a new camera body.

The new camera bodies were designed to accept the same lenses used with the old cameras. They have some new features including:

1. An integral, AC motor driven, shutter-lens cap that is relay-operated with a TTL (+5 VDC) logic signal;

2. Two printed circuit boards containing LED, seven-segment displays. The left LED board also has a 50-pin edge connector, and the right LED board incorporates a 40-pin edge connector;

3. Two blank printed circuit boards, one left- and one right-side for BRL supplied electronics.

4. Two wide angle lenses mounted internally along a folding mirror optical system used to focus the LED displays onto the film plane of the camera;

5. A new clevis-type locking mechanism for the 7-in lenses. Replaces the older set-screw method of locking the lens in place after focusing;

6. Four BNC coaxial connectors mounted on top of the camera and one 16-pin amphenol connector mounted at the top rear of the camera;

7. Internal dip switches for controlling some of the LED displays; and

8. Three open-close switches for use in camera status functions. (Shutter open, shutter closed, and film-load/unloaded).

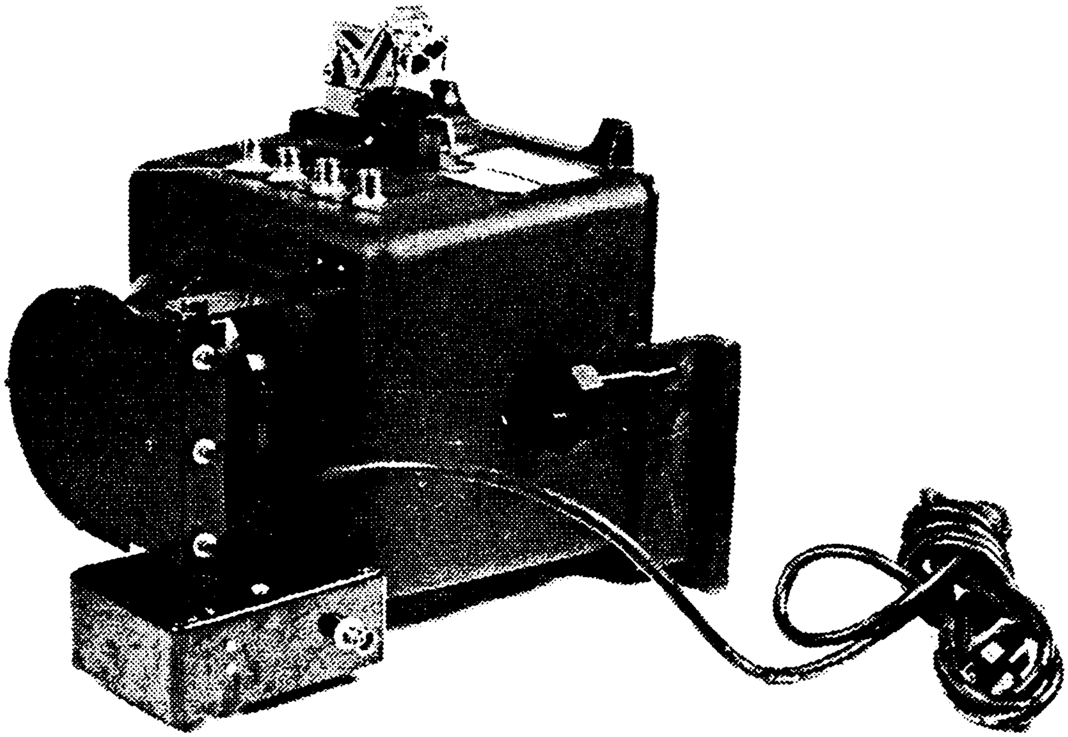


Figure 3. Photograph of Spark camera body.

The features listed above were included in the new camera bodies to add a control and automated annotation system to the Transonic Range spark photographic cameras. Control and annotation information can be sent to the range cameras from a remote site and impressed upon the film from there.

There are 13 LED, seven-segment displays mounted on two circuit boards. These display boards are internal to the camera and are located just behind the camera back. The 13 LEDs are organized into a four-digit and a two-digit group on the left side of the camera (as looking at the back of the camera) and a four-digit and three-digit group on the right side of the camera. The inputs of the LEDs for the three-digit group are controlled by dip switches located on the inside of the camera (lower right of Figure 4) and are used for setting camera location identification. Figure 5 is a photograph showing the left and right display circuit board blanks. The inputs for the other LED display groups are all connected to the 40-pin and 50-pin edge connectors shown in Figure 5. The blank circuit boards supplied with each camera are for custom-built electronic circuits for controlling the LED displays. These circuits and functions will be discussed in the next section.

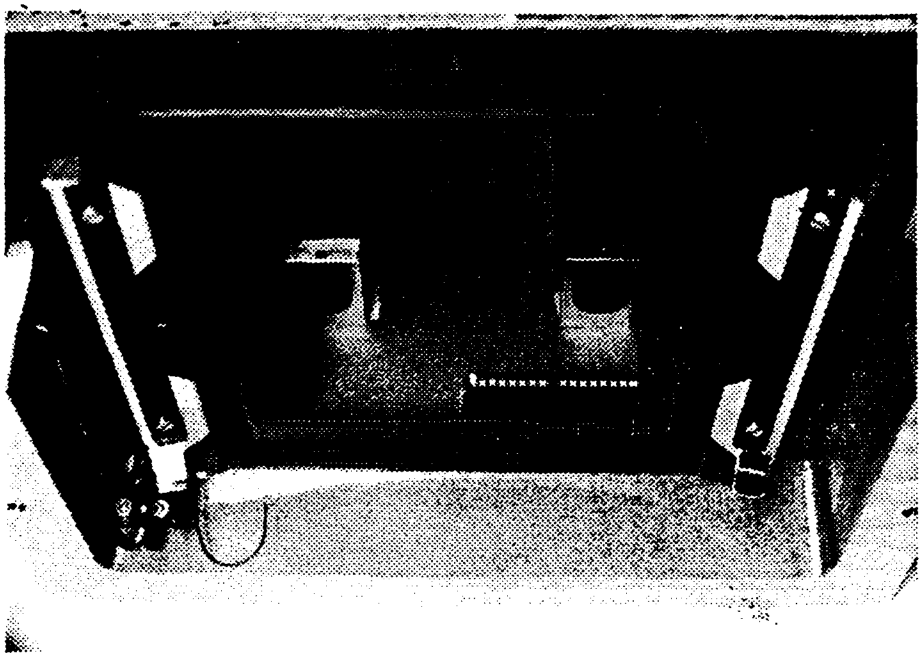


Figure 4. Photograph of spark camera showing dip switches.

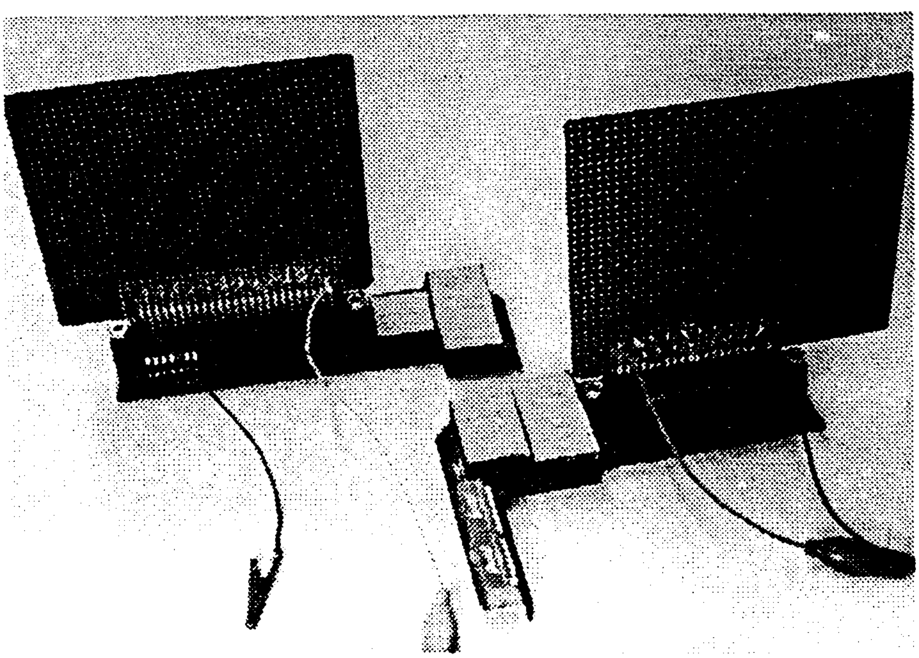


Figure 5. Photograph of blank circuit boards for controlling LED display boards.

The four BNC connectors and the 16-pin amphenol connector are provided for bringing power and control lines to each camera. One BNC connector is used to provide a 5 VDC power source for internal electronics to drive the LED displays. Another is used as a convenience for routing signals that actuate the shutter; two are not currently used. The 16-pin amphenol is used to input control signals that set and turn the LED displays on and off as well as for outputting the states of the status switches.

The wide-angle lens and folding mirror setups are used to focus the light from the LED display groups onto the film plane of the camera and are shown in Figures 6-7. Figure 6 shows the lens-folding mirrors arrangements that have been removed from a camera, while Figure 7 shows them as mounted inside the camera. Figure 8 shows a sketch of the geometry of the internal optics.

The integral shutter-lens cap assembly on each camera unit consists of a control unit, shutter post, and shutter blade assembly. The control unit is mounted on the lower left front of the camera housing. This unit consists mainly of the relay, motor, status switches, and a BNC input. The integral shutter-lens cap is controlled by a reversible AC drive motor. Application of a +5 VDC signal to a shutter control BNC connector will operate a relay that applies 110 VAC to the drive motor that opens the shutter-lens cap. When the lens cap is fully open, a limit switch closes and stops the motor. Releasing the applied DC signal voltage reverses the action and closes the shutters. Figure 3 shows the shutter in the closed position. The shutter covers the lens entrance aperture. This prevents light from entering the camera and protects the lens from dust and dirt.

Shutter status information (open or closed) is provided by separate switches. These switches are connected to positions on the amphenol connector found on the top of the camera housing. When the shutter is completely closed, the close-status switch is in the closed position. At all other shutter positions, this closed-status limit switch is in the open position. This action is reversed for the open-status switch. A film-load switch is mounted at the lower rear left side of the camera and is activated when a film holder is inserted.

As stated previously, the purpose of adding these features to the new cameras was to remotely send control and annotation to each camera so that the film could be automatically marked before or after each round fired through the range. The annotation and control system is discussed in detail in the next few sections of this report.

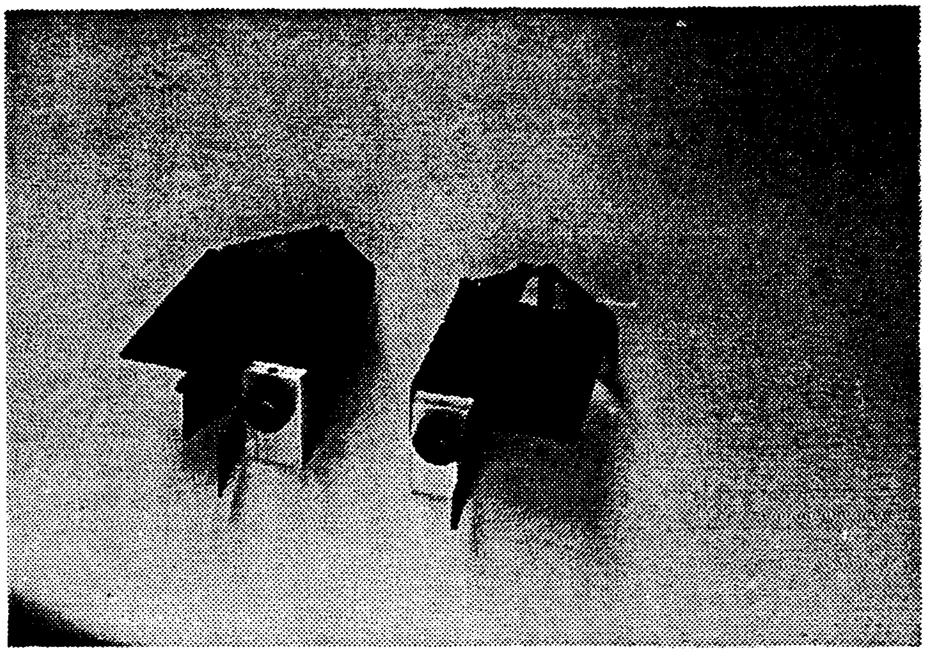


Figure 6. Photograph of wide angle lens-folding mirror assembly (removed from camera).

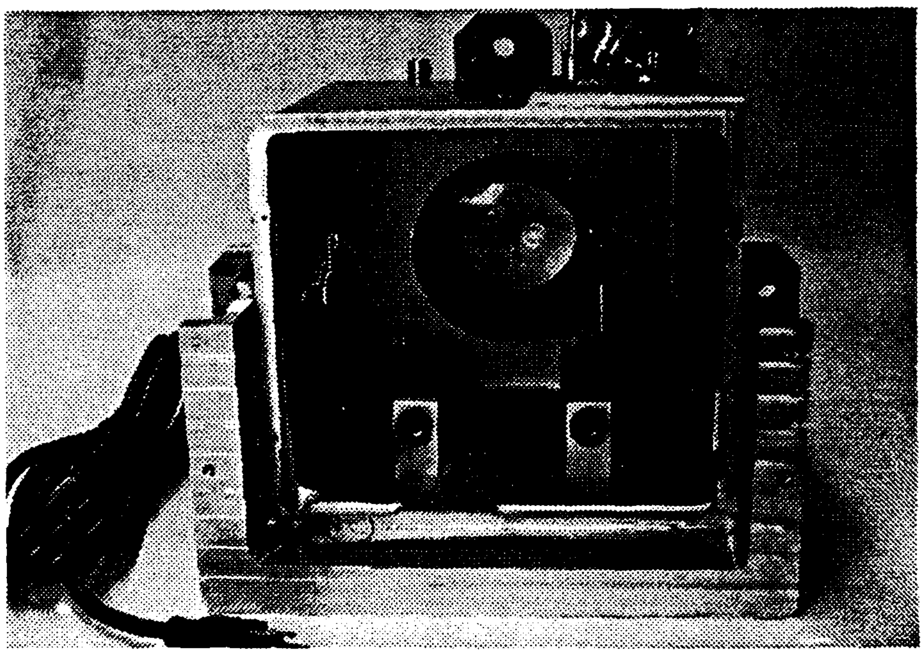


Figure 7. Geometry of internal optics.

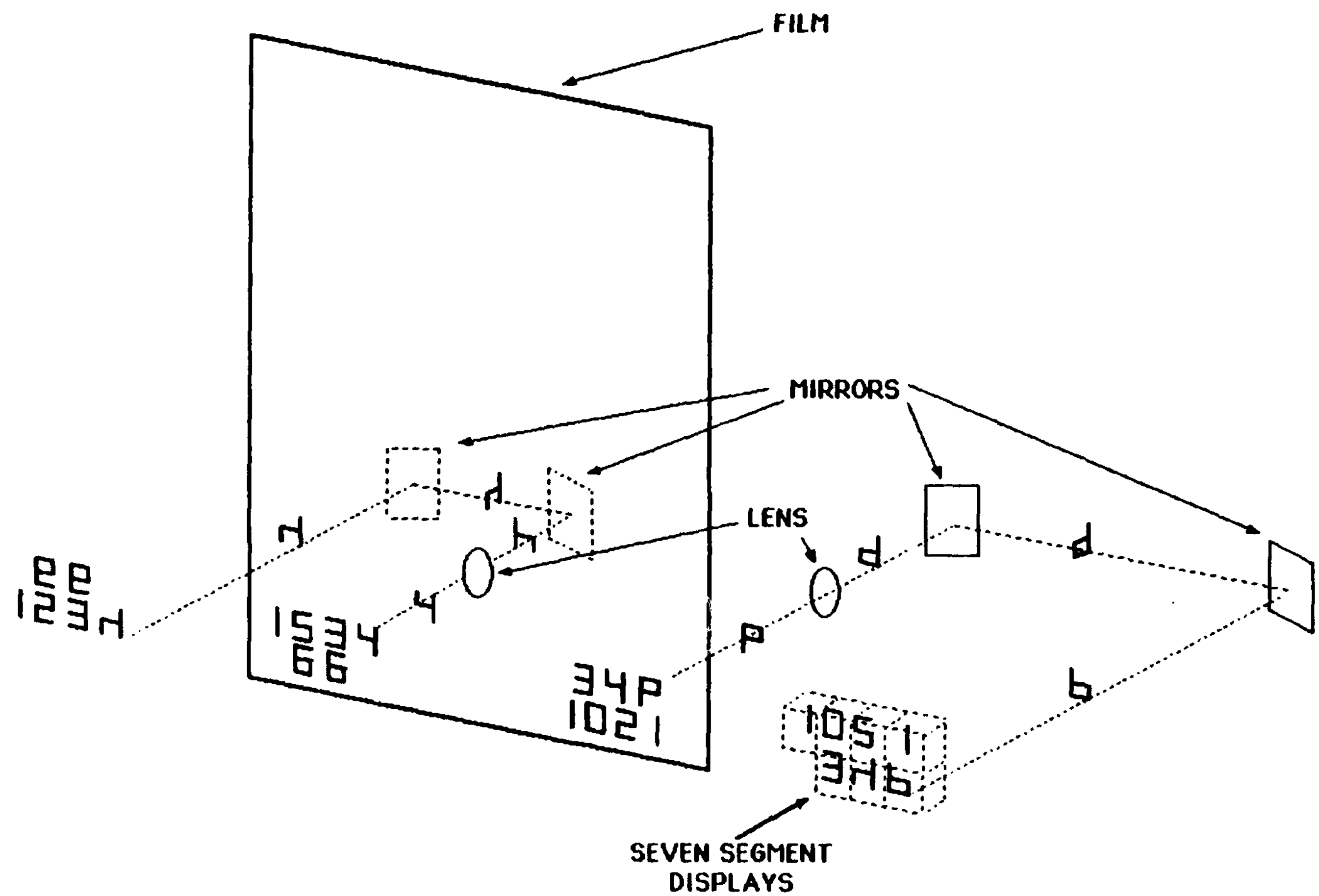


Figure 8. Geometry of internal optics.

4. ANNOTATION-CONTROL SYSTEM

The annotation control system is a combination of custom-made circuits interfaced with specialized instrumentation and a desk-top computer. The system includes circuit cards and custom-built power units installed in each camera in the range. Digital information is transmitted to these circuit cards by a Hewlett-Packard multiprogrammer, controlled by a desk-top computer. The system utilizes an IEEE-488 parallel bus and a 100-pair cable network, previously installed in the range. Figure 9 shows an overview of the annotation-control system.

4.1 Camera control circuits. As mentioned previously, the new cameras have a 13-character, seven-segment display mounted in them. The right side of the camera has a four-character display and a three-character display. A four-character display and a two-character display make up the left side. Driving the 13-character, seven-segment displays directly from a remote location requires more than 91 individual lines into each camera. Since there are 50 cameras distributed over the length of the range, this would be rather cumbersome. The most efficient way of providing annotation data to the cameras would be to install counter circuits and display drivers in the cameras themselves and then send data in the form of clock signals. For example, if the round number was 1,234, then 1,234 clock signals would be sent over 1 control line. In this way, the number of lines going to each camera was kept to a minimum of 15 control lines. A 16-pin amphenol connector on each camera provided access for the 15 control lines necessary to control the displays.

For each two-, three-, or four- character display, the following control capabilities were deemed necessary:

1. Clock counting circuits.
2. Latching capability to 'lock-in' the count to a particular display.
3. Interface from the counters to seven-segment displays (display drivers).
4. Reset capability where the display and counters could be reset to zero.
5. Exposure control to remotely turn the displays on or off.

Fortunately, there is a ttl device, SN74143, that includes a four-bit binary counter, a four-bit latch, and a seven-segment display driver all combined into one chip. The SN74143 also has pins for clearing the counter and for turning the seven-segment drivers on and off. This chip reduces the component count needed by a factor of 3:1.

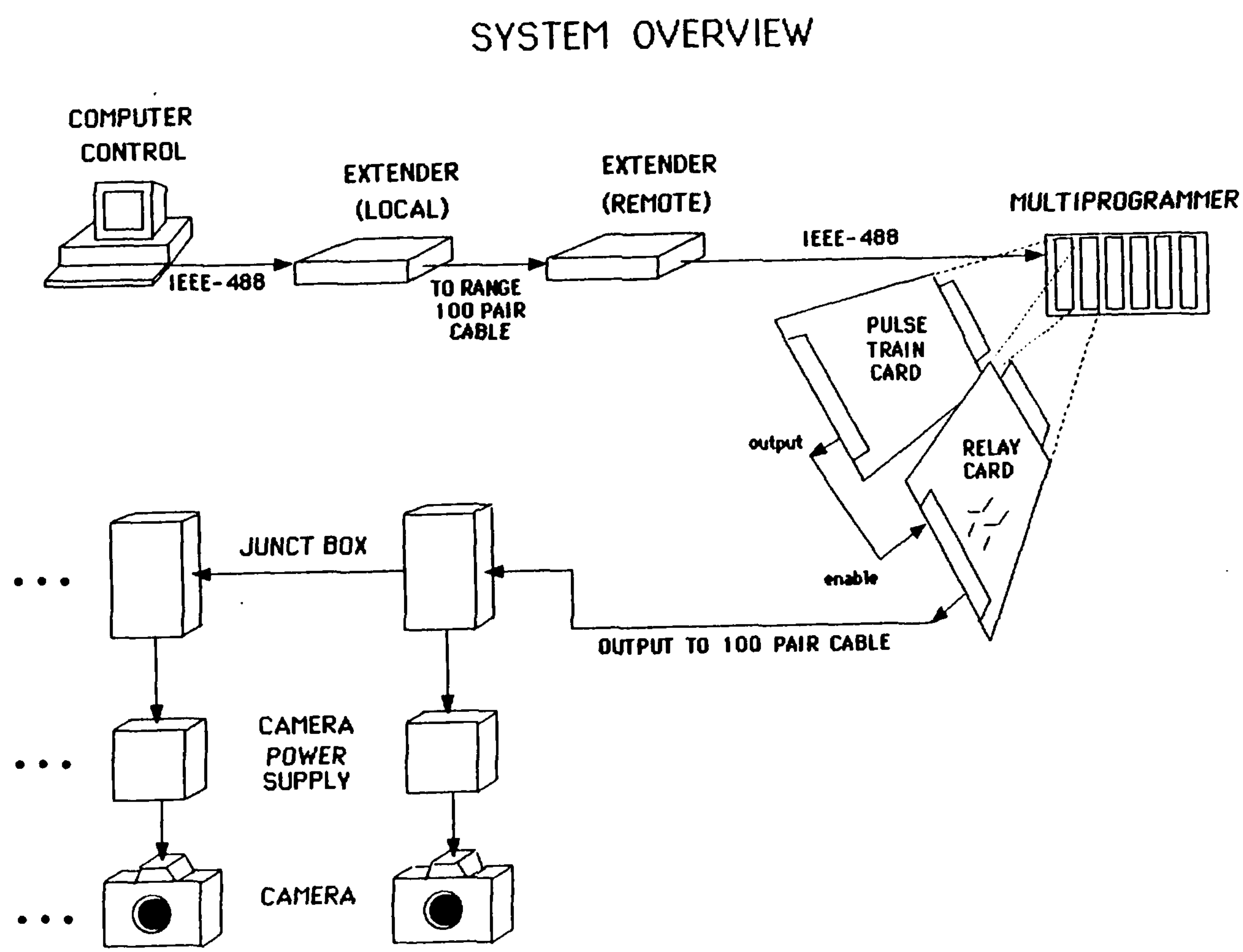


Figure 9. Overview of Spark camera annotation-control system.

Table 1 is a list of all the clock-control signals that are used by the circuits in each camera.

Figures 10-11 show a simplified block diagram of the final circuits that are placed into each camera. The circuit in Figure 10 controls the displays on the right side (as seen from the rear of the camera body). This includes a four-character display used for month and day information and a three-character display used for station ID purposes. The only controls for the three-character display are exposure (on-off) and dip switches mounted in the camera. The only time the dip switches are changed is if the camera body is removed from the range and replaced.. The diagram in Figure 11 is for the left-side camera board. This board has two control circuits, one for a four-character display and one for a two-character display. These two displays are used together to send round number annotation to the cameras. For example, if the round number is 22,937 then 22 clock signals are sent to the two-digit counter and 937 clock pulses are sent to the four-digit counter. This method of splitting the round number into two parts allows the present transonic range numbering scheme to remain in effect.

TABLE 1. Clock and Control Signals.

Control line	Type*	Display	BOARD
clock1	momentary	date	right
clear1	momentary	date	right
Latch1	constant	date	right
clock2	momentary	round #	left
clear2	momentary	round #	left
Latch2	constant	round #	left
clock3	momentary	round #	left
clear3	momentary	round #	left
Latch3	constant	round #	left
Exposure	momentary	all	both

* Where momentary is a short duration or pulse action and constant means that the control line is held in either a high- or low-logic state.

It can be seen in Figures 10 and 11 that all the clock-control lines to the left and right camera boards are held in a normally high logic state using a resistive divider. This allows for the clock operations and other control functions to be accomplished with contact closures at a remote site. This is advantageous since each of the control lines specified in Table 1 has to simultaneously go to 50 cameras distributed over 230 m. Sending clock and control signals

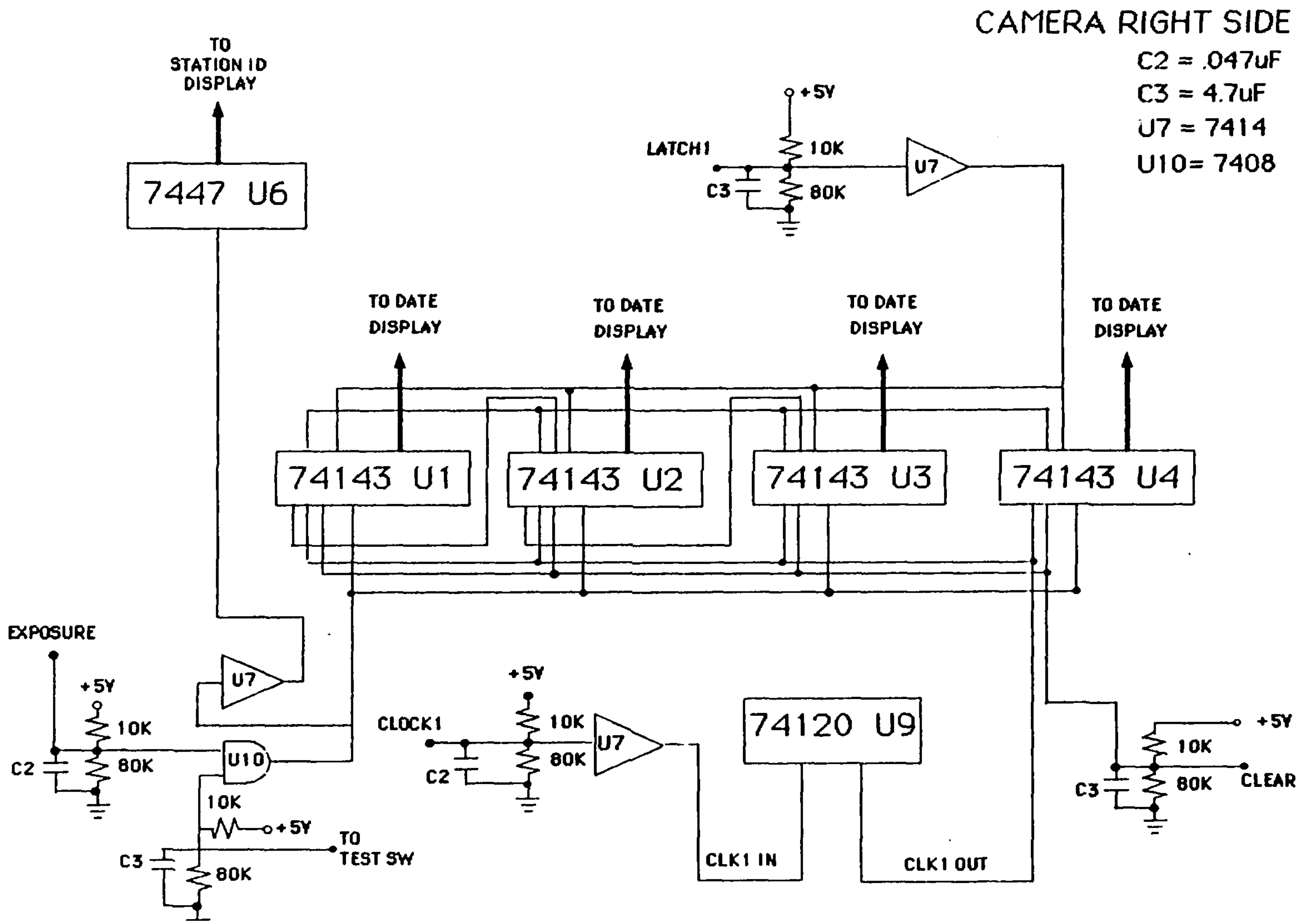


Figure 10. Block diagram of right side of display control circuit.

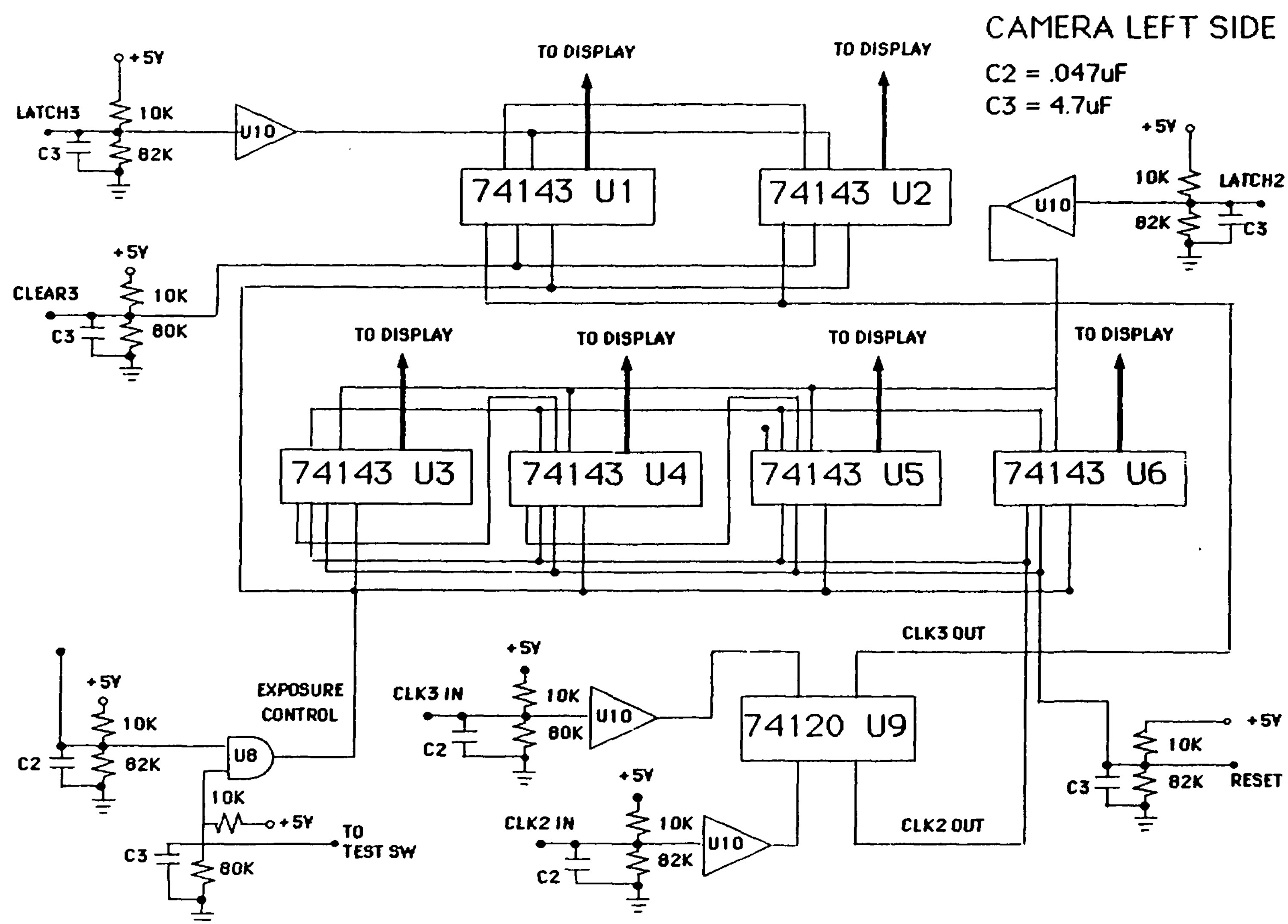


Figure 11. Block diagram of left side of display control circuit.

to the cameras in the form of voltage pulses instead of contact closures could be difficult. There were anticipated problems from the noise on the interface lines or from the frequency response affected by the long distances involved. Each camera was provided with its own power supply, and the control inputs were held at a high logic level so that the clock and control functions could be accomplished in the form of contact closures at the controller site, which is remote to the cameras.

4.2 Multiprogrammer control. A Hewlett-Packard model 6942A multiprogrammer is used as the mechanism for sending annotation data to the camera circuits. The multiprogrammer is a 16-slot main frame device that accepts a variety of plug-in function cards. The multiprogrammer has an IEEE-488 interface built into it and is used to communicate with a desk-top computer or a personal computer with a similar interface. Each slot in the multiprogrammer is addressable by the desk-top computer via the IEEE-488 interface. Each plug-in function card has a set of instructions that can be sent by the desk-top computer and executed by the cards. Figure 12 is a drawing of the back of the multiprogrammer showing the particular function cards that are used in the camera system. Table 2 lists the plug-in cards and their application function in the camera system.

TABLE 2. Control Multiprogrammer Function Cards.

Slot ID	Card type	Card functions
0	pulse train	enable relay cards
1	relay card	contact closures for clock, clear and exposure functions
2	relay card	contact closures for latches
3	bread board	custom interface circuits and 5-V DC source for shutters
4	relay card	contact closures for shutter-control relays

The plug-in relay cards have 16 independent double-pole, single-throw switches on each card. The switches can be opened or closed as a group or individually by sending an appropriate command from the desk-top computer. The relay cards themselves can be operated in several ways. One way is to keep the card enabled all the time and send a command to close the desired

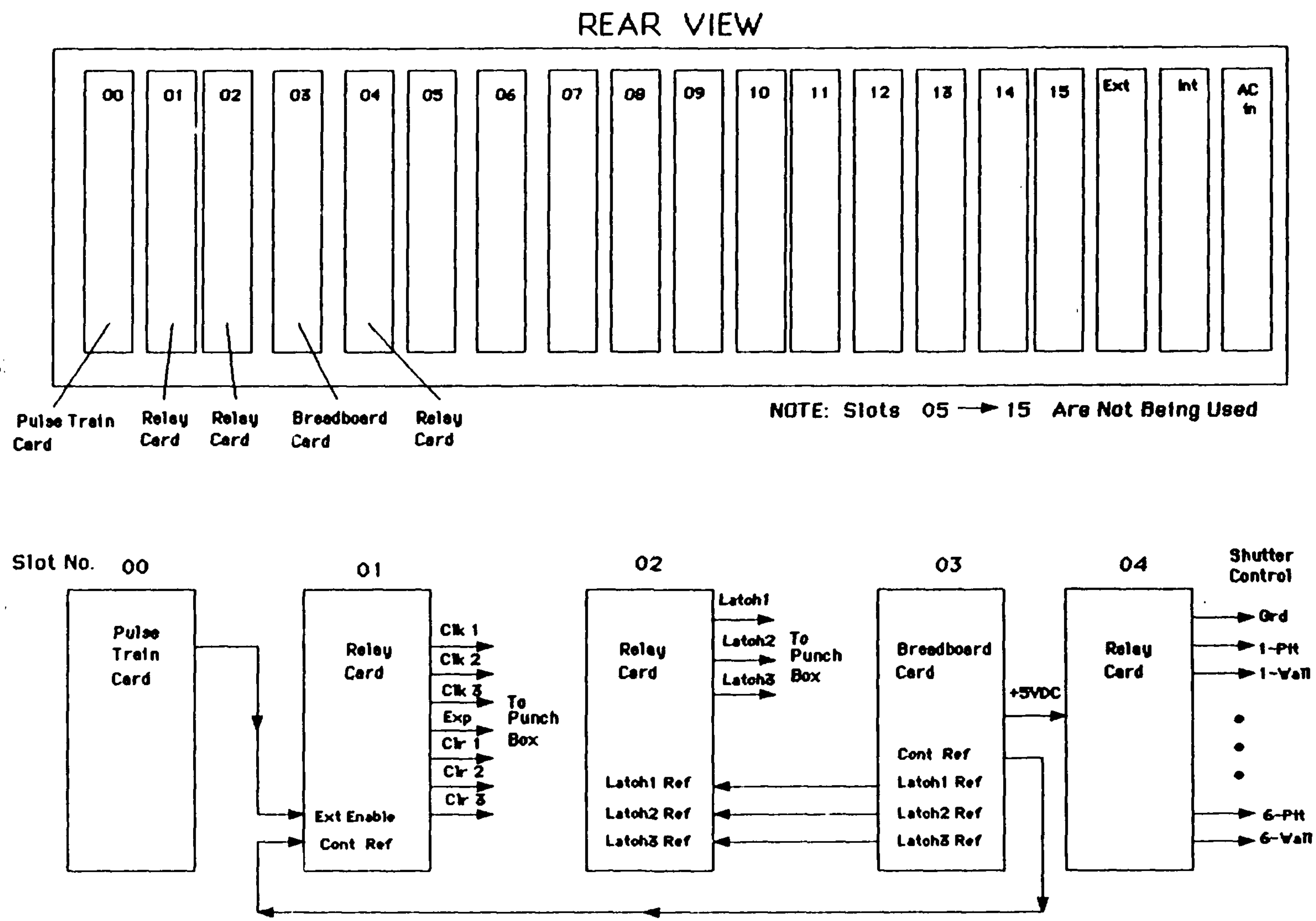


Figure 12. Block diagram of control multiprogrammer function.

switches. In this mode, the switches stay closed until an 'open' command is sent. This is the mode used for the latch relay cards and the shutter-control relay cards since it is desired to hold these states until released by the program. The second mode of operating the relay cards is to keep them disabled and to send a command to close the desired switches. The switches don't actually close until the cards are enabled. The pulse-train card is used to provide the enabling. This mode is used for the clock, clear, and exposure contact closures since these control lines require a 'momentary switch action' to actuate the counting circuits in the cameras. The procedure for sending date or round number information to the camera circuits is to send a command to close the proper switch on the relay card in slot 1 and then to command the pulse train card to output the appropriate number of ttl pulses that, in turn, open and close the relay contacts. Since the clock and control lines are normally held in a high logic state, opening and closing the relay switches appear as clock signals to the counting circuits in the cameras. The exposure line isn't counted in the cameras, but it too requires a momentary action to turn on the LED displays for a short period of time (about one millisecond) in order to impress annotation data onto the film. The pulse train card is programmable in both the number of pulses it can generate and in the period (for one pulse) or rate (for multiple pulses). The pulse rate used in the camera application program is 200 Hz.

4.3 Camera power supply and connections. There was a 100-pair cable installed throughout the TRF just before the camera system was started. The cable provided an ideal method of interfacing the camera circuits to the multiprogrammer since the desk-top computer and multiprogrammer are located remote to the cameras, and the cameras themselves are distributed in 25 stations throughout the 730 m of the range.

The cable originates in building 740B and is underground between building 740B and the range. It enters the range at group one and is enclosed in steel conduit inside the range. It exits the range and continues underground to the X-ray facility at 1,000 m from the ramp. Inside the range, there is a spur or parallel cable leading to the chronograph room exterior to the range proper. The desk-top computer and multiprogrammer are located in the chronograph room. Access to the cable is provided at each of the 25 camera stations by a junction box containing four 50-row telephone punch blocks. Each line of the cable is attached to punch blocks at each station.

The clock-control lines coming out of the multiprogrammer are assigned to positions on the punch block in the chronograph room. These positions are common to all the stations throughout the range. A 16-wire cable is hard-wired to each camera power supply box and is run though a conduit under the range floor (for pit cameras) or down the wall (for wall cameras) to the junction box at each station. This cable is enclosed in an armored sheath to provide protection for any

exposed section. Figure 14 shows a typical punch block hookup for a camera station. Note that there are 10 lines dedicated to the ttl common, which is the DC ground for the power supplies in each camera power unit. These ten lines were tied in parallel at each junction box in order to minimize line loss effects. The ttl ground of the multiprogrammer is also tied to these 'common' lines. A short jumper is provided between the camera supply boxes and the amphenol connector on the camera to complete the hookup. This scheme of connecting the cameras keeps the amount of exposed cable to a minimum in the event that a shell or sabot fragment hits a station. Unless a wall junction box is hit directly, the most that would probably have to be replaced would be the short jumpers between the cameras and the power units.

A separate power unit was built for each camera in the range. This power unit provides for 5 VDC for the circuits in the cameras. The power units also serve as an interface between the amphenol connectors on the cameras and the 100-pair cables on the wall of the range. A schematic of a typical camera power unit is shown in Figure 13.

Using the power units as a throughput for the signal lines also serves another purpose. They isolate each camera from one another. Each signal line goes to 50 cameras. This means that each camera is tied to each other and a failure in one camera could adversely affect the whole system. In order to provide some isolation between lines that share a common position on the 100-pair cable, a diode is inserted in series with each control line before it goes into the camera. This is physically done inside the camera power units. Therefore, a short to ground, for example, in one camera remains local and will not pull that position low on the 100-pair cable and affect the other cameras. Although the diodes provide some degree of isolation between cameras, they also introduce some additional complication in that there is an inherent voltage drop across the diode of 0.6 - 0.8 V. Closing a relay switch in the multiprogrammer relay card causes the voltage on that position on the 100-pair cable to be dropped from a ttl high to a near-zero volts, ideally. This was true for those stations near the chronograph room. However, for those stations near the end of the range, this near-zero voltage was closer to 0.1-0.2-VDC. This is because the camera system is a distributed system and line resistance is not negligible. This, coupled with the inherent 0.6- to 0.8-V drop in the diodes, resulted in inconsistent and unreliable operation of the cameras at the end of the range. The logic levels on the camera boards themselves would drop from a high level of 4 V to a low logic level of approximately 1 V, which is not low enough for the ttl components in the camera circuits to change logic states. For this reason the control lines on the 100-pair cable had to be driven to a negative voltage (relative to ttl ground) in order to get reliable and consistent operation throughout the range. This negative reference was generated by a custom circuit built onto the breadboard card in slot 3. This circuit is shown in Figure 15.

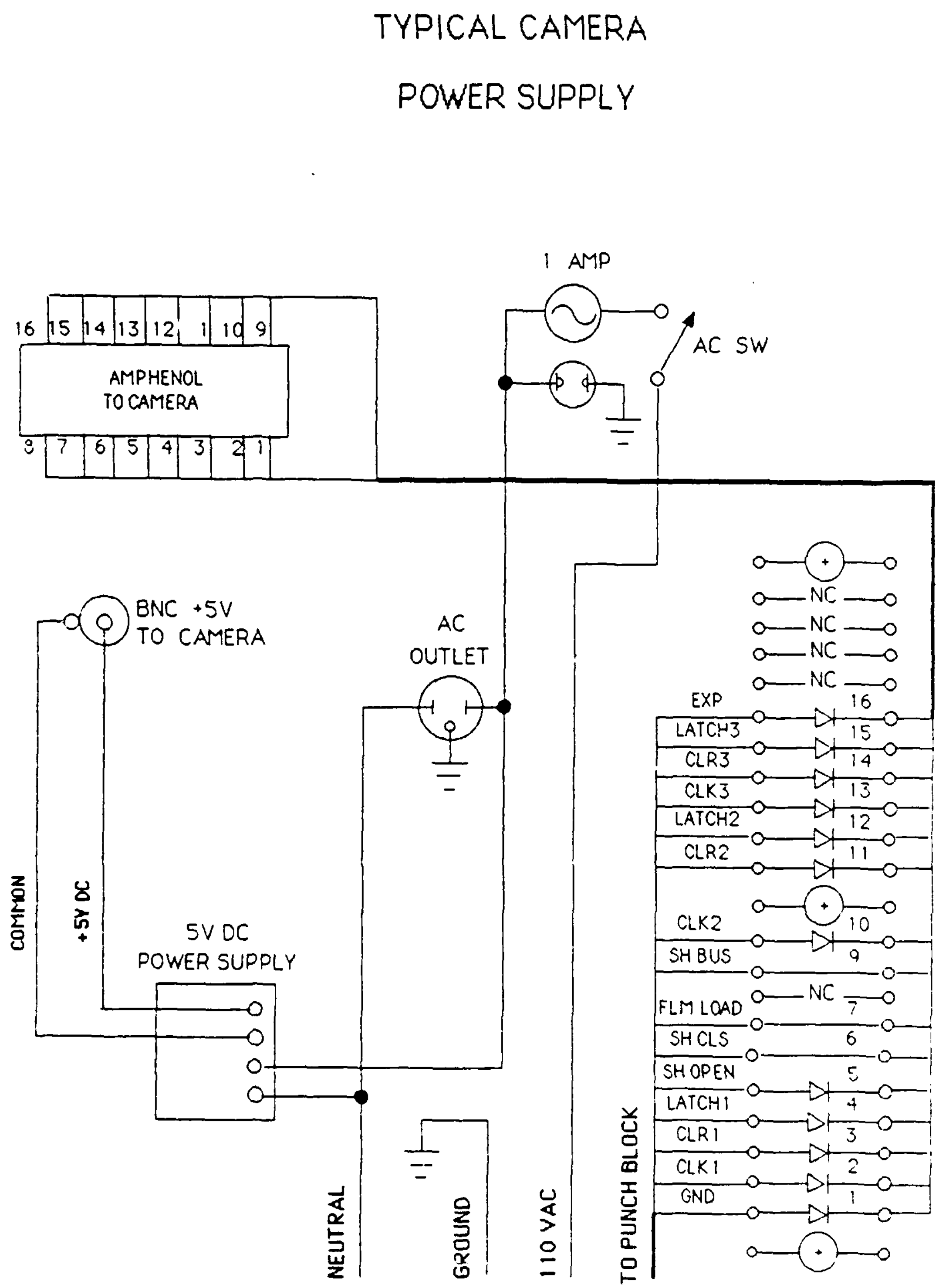


Figure 13. Typical camera power supply.

transonic range camera system: location: Transonic Range
station : (non-mid group) 1-1

block B (top right)					block A (bottom right)			
	pair					pair		
shut open	W bl/wh	bk	*	50			bk	*
		br	*	49			br	*
		bk	*	48			bk	*
		or	*	47			or	*
		bk	*	46			bk	*
shut open	P bl/wh	gn	*	45			gn	*
		bk	*	44			bk	*
		bl	*	43			bl	*
		bk	*	42			bk	*
		sl	*	41			sl	*
		br	*	40			br	
		rd	*	39			rd	
		br	*	38			br	
		yl	*	37			yl	
		br	*	36			br	
		vi	*	35			vi	
		br	*	34			br	
		wh	*	33			wh	
		rd	*	32			rd	
		or	*	31			or	
shut close	W wh/bl	rd	*	30			rd	
		gn	*	29			gn	
		rd	*	28			rd	
		bl	*	27			bl	
		rd	*	26			rd	
shut close	P wh/bl	sl	*	25			sl	
		or	*	24			or	
		yl	*	23			yl	
		or	*	22	w shutter	W	or	*
		vi	*	21	p shutter	P	vi	*
		or	*	20	exposure	P,W	or	
		wh	*	19	clock 3	P,W	wh	
		yl	*	18	clock 2	P,W	yl	
		gn	*	17	clock 1	P,W	gn	
		yl	*	16	clear 3	P,W	yl	
		bl	*	15	clear 2	P,W	bl	
		yl	*	14	clear 1	P,W	yl	
		sl	*	13	latch 3	P,W	sl	
		gn	*	12	latch 2	P,W	gn	
		vi	*	11	latch 1	P,W	vi	
film load	W sl/wh	gn	*	10	wall gnd	I,W	gn	ttl gnd
		wh	*	09	pit gnd	I,P	wh	ttl gnd
		bl	*	08		I	bl	
		vi	*	07		I	vi	
		bl	*	06		I	bl	
film load	P sl/wh	wh	*	05		I	wh	
		vi	*	04		I	vi	
		sl	*	03		I	sl	
		sl	*	02		I	sl	
		wh	*	01		I	wh	

Figure 14. Typical punch block hookup.

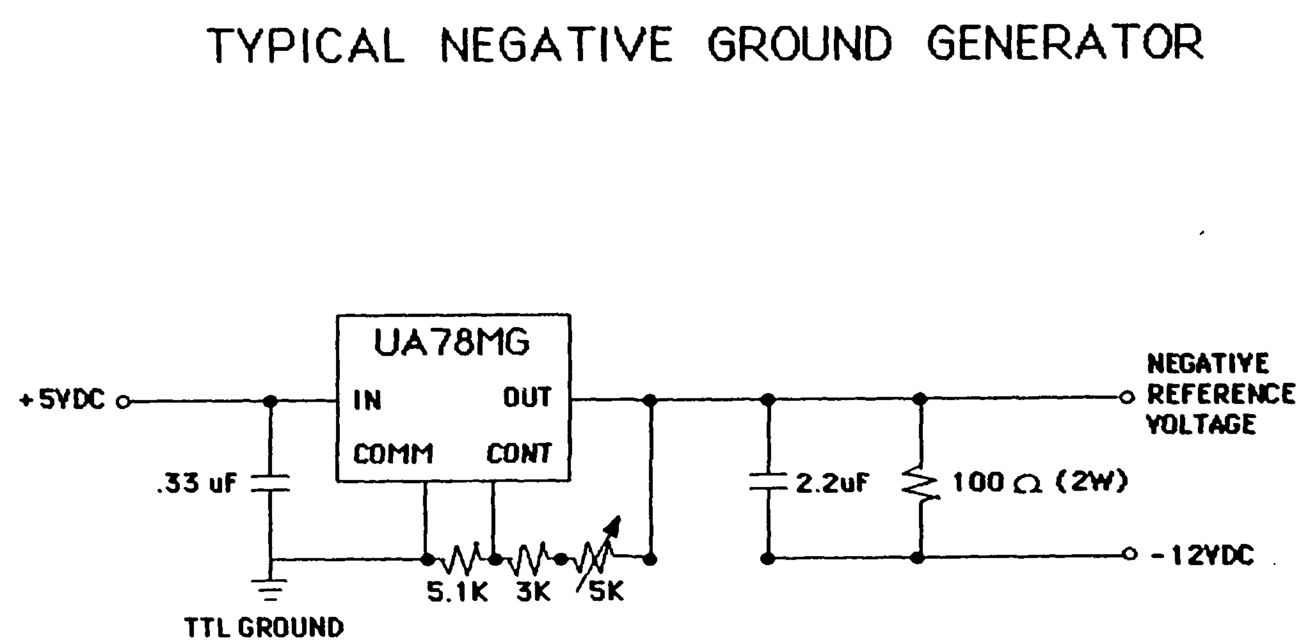


Figure 15. Negative reference circuit.

4.4 Shutter power supply and shutter operation. Each camera has been equipped with an electronic shutter assembly supplied by the Image Technology Corporation. This assembly is used to shield the film from unwanted light, to act as a dust cover, and to protect the lens when the system is not in operation.

The shutter assembly consists of an electronic control box, post, and blade. This entire assembly is mounted on the front of the camera and positioned such that the shutter blade completely covers the lens when closed. The control unit housing serves as a base for the post and blade mechanism. This unit contains a DC-operated relay (5 VDC), a 110 VAC reversible clock motor to drive the shutter blade, and a set of limit switches that stops the shutter blade in the fully-open position or the fully-closed position. Figure 16 is a photograph of the shutter control assembly.

The shutter can be controlled remotely by applying an external 5-ttl signal to the BNC connector. When this signal is applied, the shutter blade will rotate 180 degrees to the opened position. A limit switch will then disconnect the 110-VAC source causing the shutter to automatically stop. Removing the signal causes the shutter to rotate back to the closed position. Again, a limit control switch automatically stops the shutter in its proper position. These limit switches were preset during camera installation.

A second set of switches located in the control box are actuated (closed) when the shutter blade is in either a fully-opened or fully-closed position. These switches are used to remotely monitor the status of the shutter and can be used to detect a stuck or partially opened shutter. These status switches and their connection to the computer system will be discussed in a later section.

In the early design stages there were several problems which had to be taken into consideration. The impedance of the coil in a single-shutter control box is approximately 500 Ω. If all 50 cameras in the range were to be controlled by a single power supply, the effective coil impedance would be 10 Ω. The total current required would be 0.5-ADC. At this level of amperage, voltage drops would occur throughout the range due to significant line resistance. To account for line losses, a single, remote power supply for the shutters would have to be greater than 5 VDC. Voltage regulation would also be required in each camera to insure consistent and reliable operation. It was decided to construct external shutter control power units that could be activated remotely via the computer-multiprogrammer system. There is one unit located in the center of each group in the range. Line losses were minimized by using this separate power control unit.

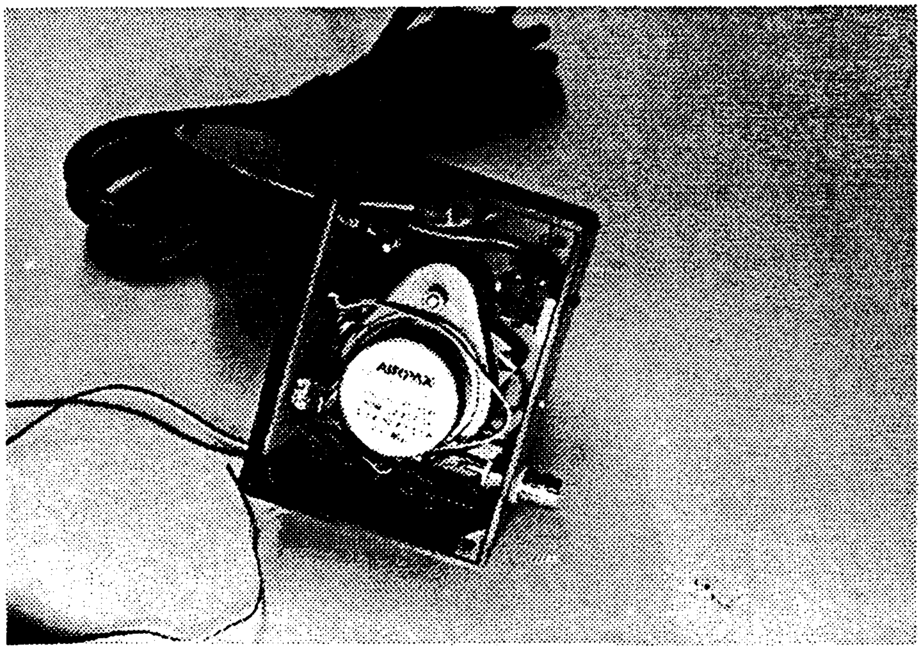


Figure 16. Photograph of shutter control assembly.

Figure 17 is a schematic of a typical shutter control power unit. Basically, it consists of two DIP relay packages and a 5 VDC power supply. This circuit box allows the shutters to be controlled remotely via the computer-multiprogrammer or manually at each group site. The external shutter control unit is hard-wired in series with the shutter control lines. The inputs of the relays are connected to the 100-pair cable lines that are allocated to the shutter control relay card in the multiprogrammer. The outputs then run to their respected control lines for pit and wall operation.

The external shutter power units allow for the complete or partial operation of the shutters. That is, individual groups can be operated if the entire range is not needed.

There are on-off switches on the sides of each external shutter power unit allowing the pit and wall shutters of a particular group to be opened manually. This allows for on-site maintenance and testing of the cameras.

4.5 Status switches and status multiprogrammer. Each range camera has three status switches. These switches are contact closures that are actuated by the shutter or film holder.

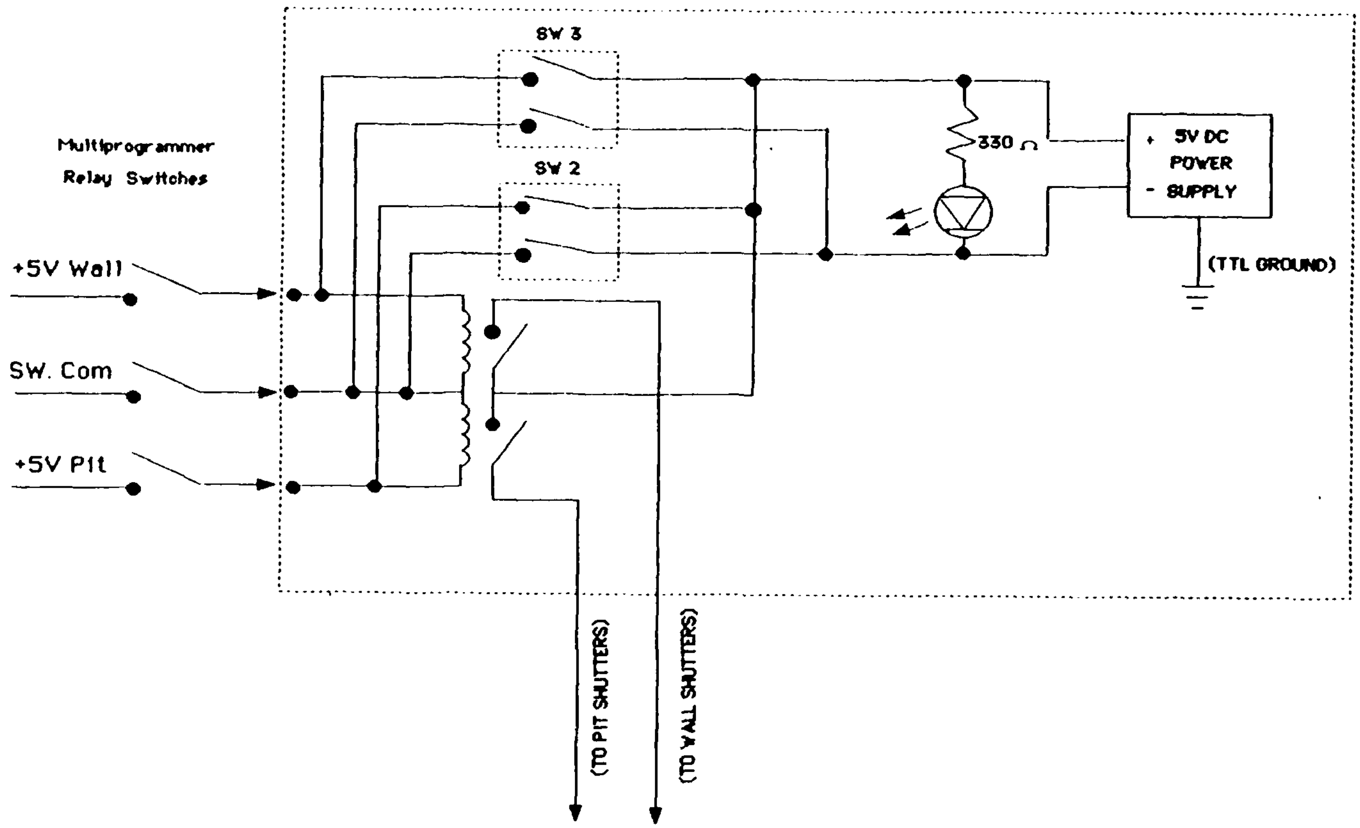


Figure 17. Typical shutter power supply box.

There are individual switches that indicated when the shutter is fully open or fully closed and a switch that closes when film is loaded into the camera. There is a second multiprogrammer located in the pit of group three (see the photograph show in Figure 18). The status switches from each camera are run back to this multiprogrammer and connected to a position on an interrupt-type, plug-in function card. The inputs to the interrupt card are normally at a high ttl level and are pulled low when a status switch contact is closed. Each interrupt card has 16 inputs, but the higher six inputs are masked, or tied low. The system controller can communicate with each interrupt card via the multiprogrammer and the IEEE-488 interface bus.

By examining (remotely) the 10-bit word that represents the logic states of each of the 10 inputs to the interrupt cards, the condition of each shutter in the range can be ascertained. Figure 19 shows a sketch of the organization of the status multiprogrammer. All the shutter-open contacts within a group are attached to a single interrupt card, so that a card is dedicated to each group. The same is true for the shutter-closed switches and the film-load switches. The cards are arranged so that the shutter-open switches occupy the first five slots; the shutter-closed cards occupy the next five slots; and film-load, the last five.

A typical check-status operation would be to read, for example, the 10-bit word on the card in slot 0 and the 10-bit word on the card in slot 5 (this would be for group 1 cameras). Bits 0-4 of each word are for the wall cameras and bits 5-9 are for pit cameras. If the value of the word from slot 0 is 1,023 and from slot 5 is 0, then all the shutters in group 1 are fully closed. If the values are reversed, then all of the shutters in group 1 are fully opened. The values of 1023/0 or 0/1023 are the only two combinations of values that indicate valid shutter operation. Any other set of values indicates either that the shutter is stuck in a partially open state or that there is a malfunction in the status switches themselves. In either case, the camera that has a faulty status reading can easily be identified by doing a bit analysis on the values of the words read back from the interrupt cards.

4.6 Results and comments. Figures 20-24 show some typical waveforms obtained while the system was in operation. These traces were obtained with a digitizing oscilloscope attached to the appropriate positions on the 100-pair cable at station 2-3 (just outside the chronograph room), the nearest station to the controller, and at station 5-5, the last station currently in the range.

Figures 20A and 20B show parts of a typical clock pulse produced by a relay contact closure in the control multiprogrammer. Figure 20A was obtained from the punch block for station 2-3 (third camera in second group) and Figure 20B for station 5-5. The circuits in the camera

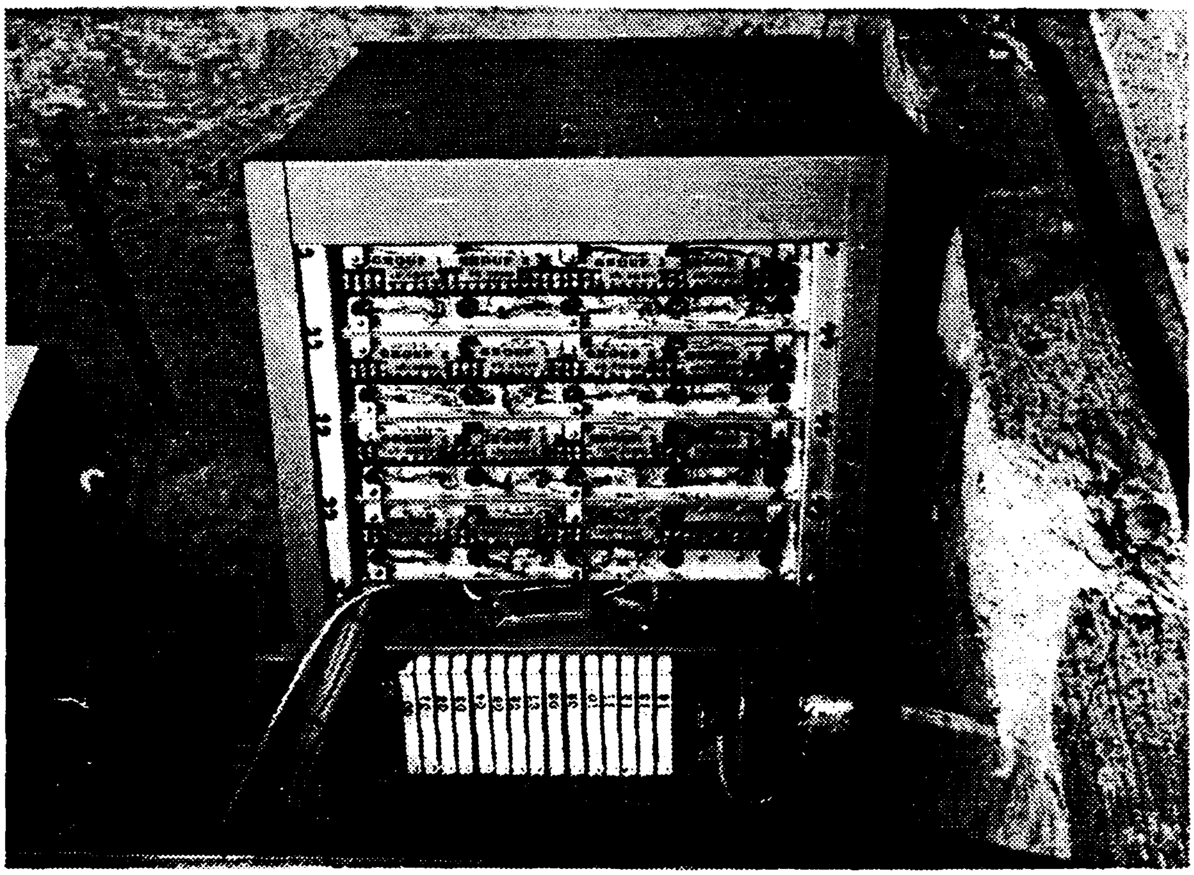
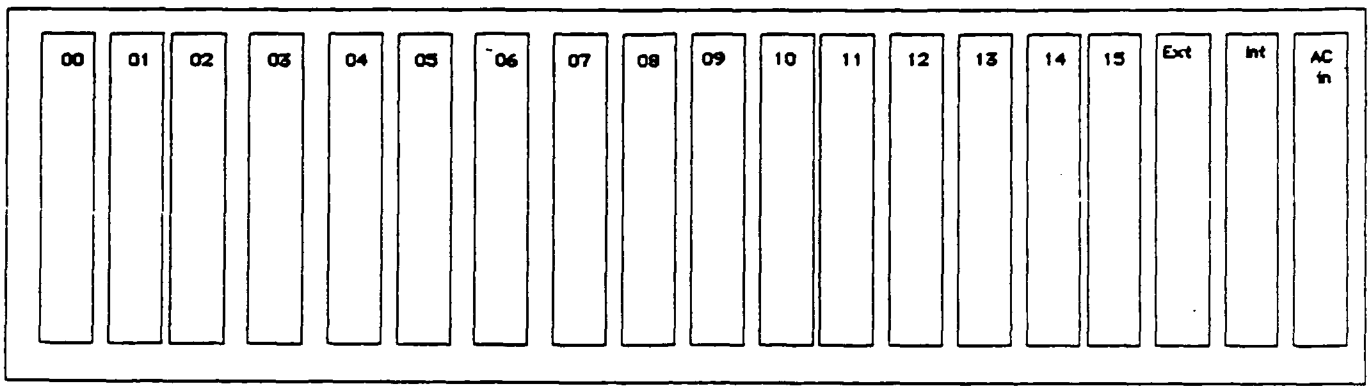


Figure 18. Photograph of status multiprogrammer located in pit 3.

REAR VIEW



SLOTS	FUNCTION
00 - 04	Shutters Open; Groups 1 - 5
05 - 09	Shutters Closed; Groups 1 - 5
10 - 14	Film Load; Groups 1 - 5

NOTES: Interrupt Cards (HP Model No. 69776A) Are Installed In Slots 00 - 14
Slot 15 Is Not Used

Typical Of All Interrupt Cards:

Output Bits	00 - 04	Wall
Output Bits	05 - 09	Pit
Output Bits	10 - 14	Tied Low

TYPICAL STATUS CONNECTIONS

Interrupt Card In
Status Multiprogrammer
(Instrument Rack Pit 3)

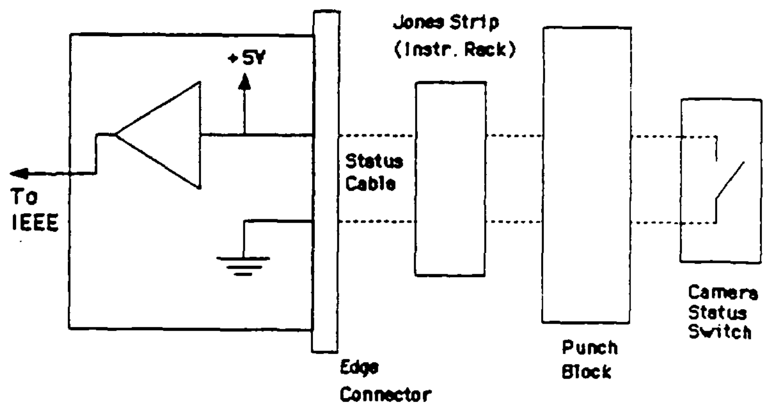


Figure 19. Block diagram of status multiprogrammer function.

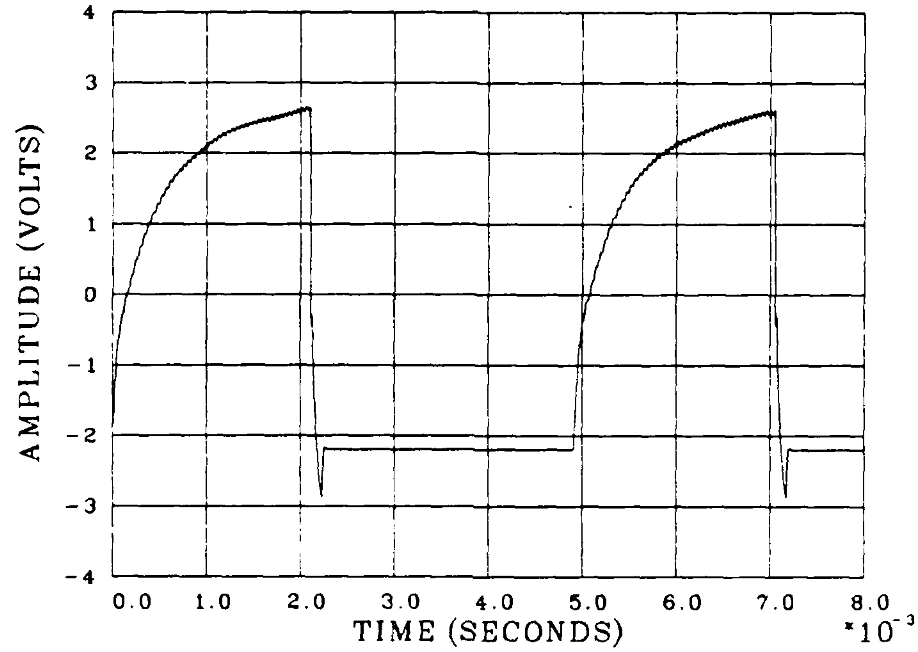


Figure 20A. Clock 1 signal (station 2-3).

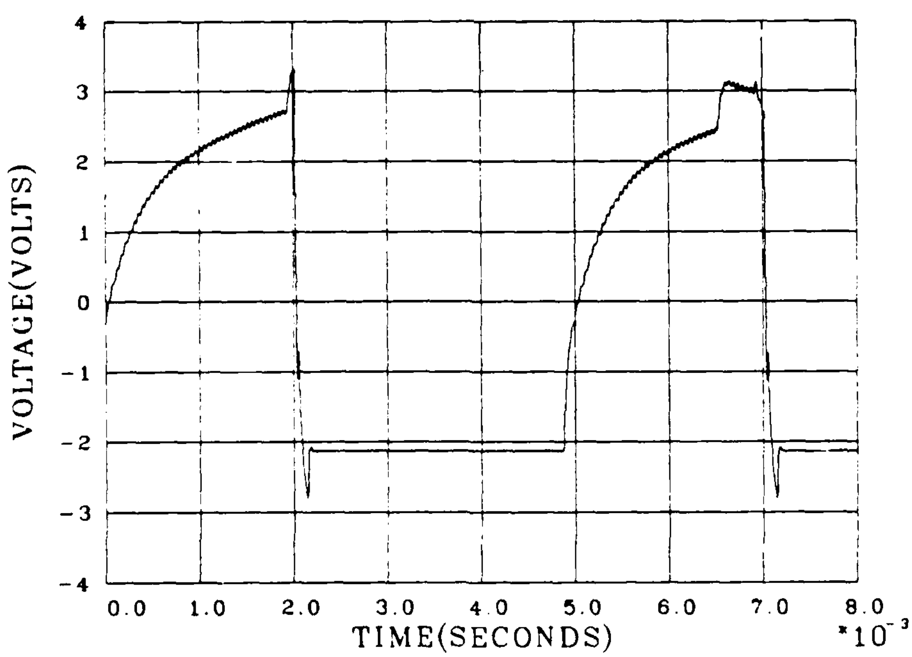


Figure 20B. Clock 1 signal (station 5-5).

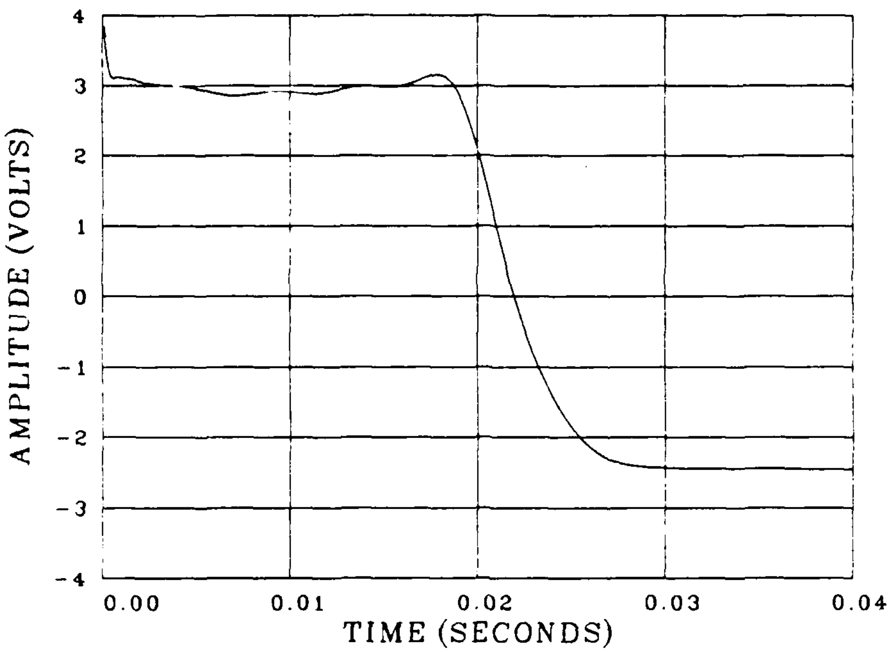


Figure 21A. Latch 1 signal (station 2-3).

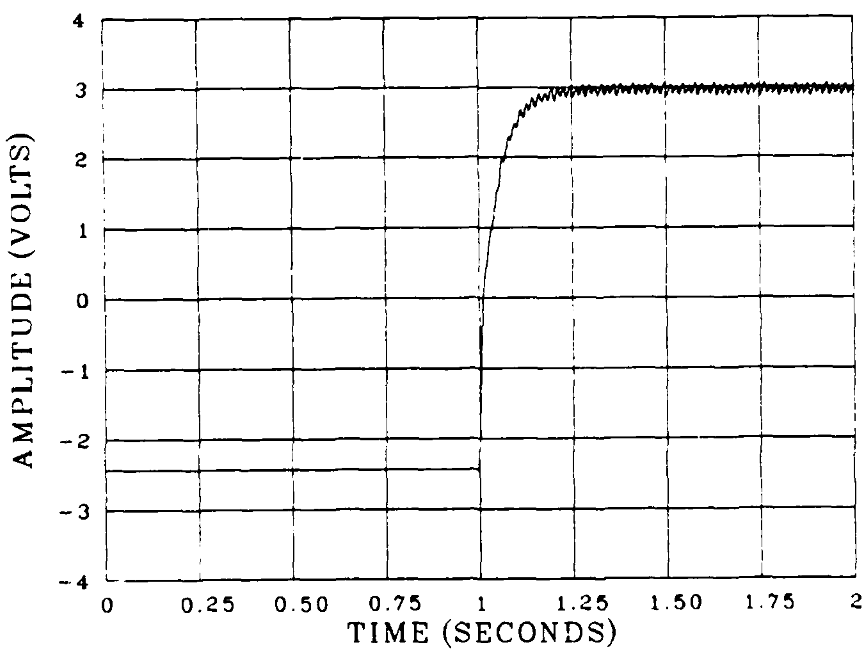


Figure 21B. Unlatch 1 signal (station 2-3).

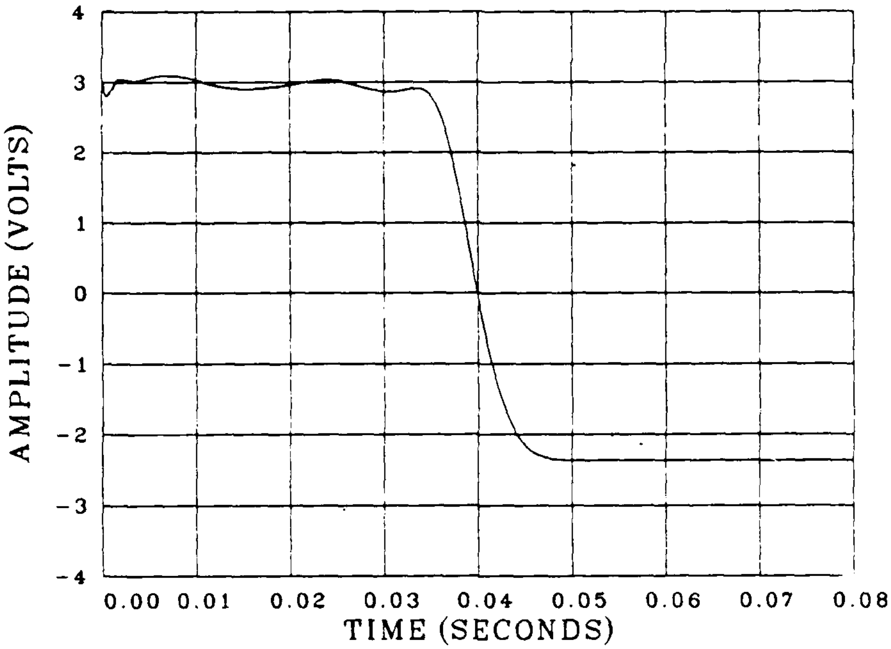


Figure 22A. Latch 1 signal (station 5-5).

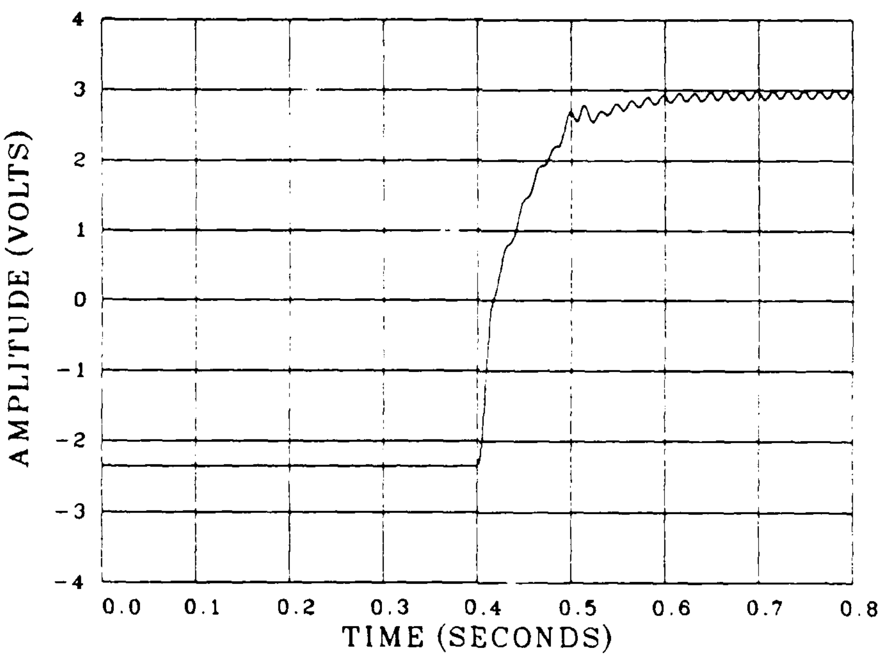


Figure 22B. Unlatch 1 signal (station 5-5).

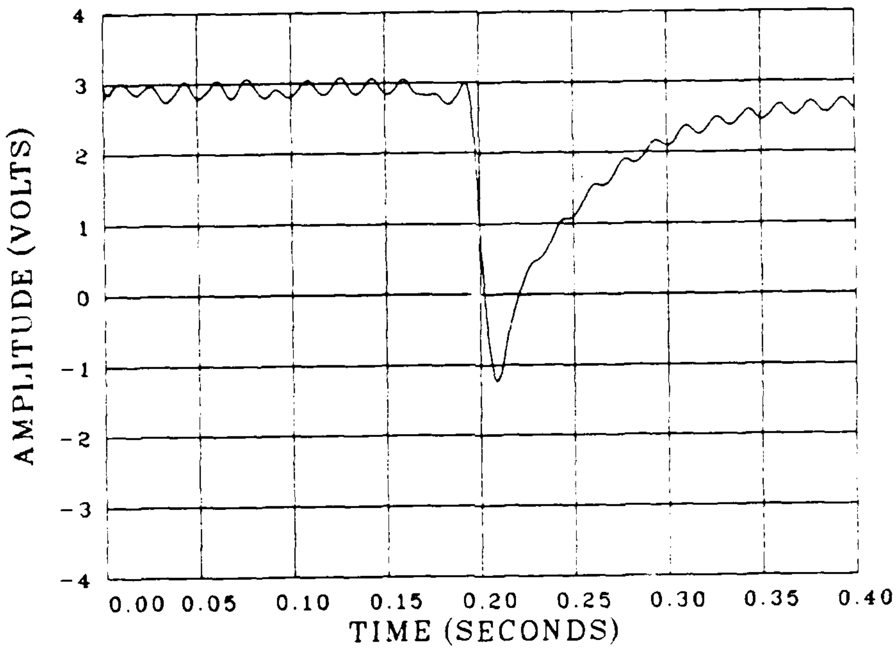


Figure 23A. Clear 1 signal (station 2-3).

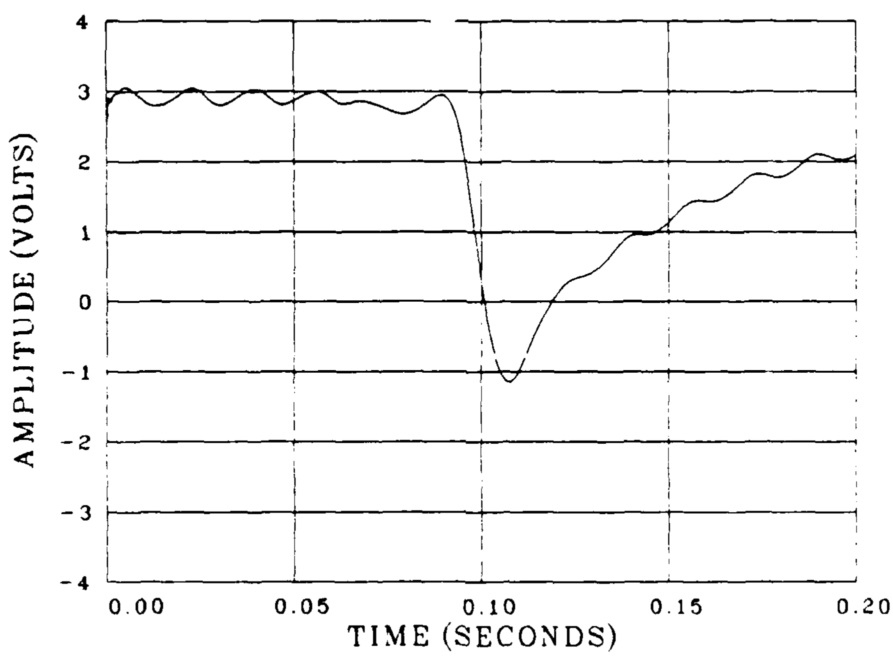


Figure 23B. Clear 2 signal (station 5-5).

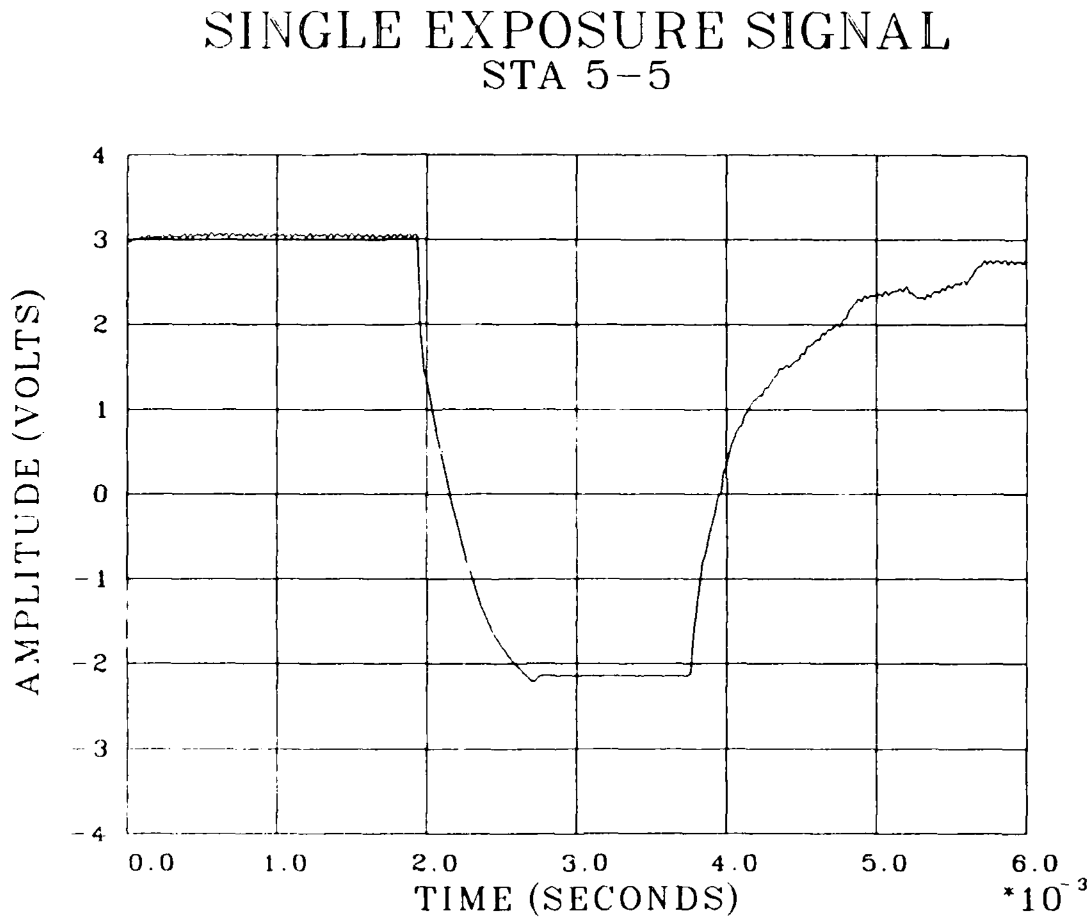


Figure 24. Single exposure signal (station 5-5).

trigger on the lagging edge of the waveform. The repetition rate for this clock signal is approximately 200 Hz, which is close to the maximum response of the relays on the relay card in the multiprogrammer. The rounded leading edge is caused by a capacitor placed on the camera circuit board to filter noise off the input line. The signal for station 5-5 shows a noise signal riding on top of the clock signal. The source of this signal hasn't been located yet, but its presence doesn't affect the operation of the system. It should be noted that this clock signal was available to 50 cameras simultaneously. Figures 21-23 are traces for the latch, unlatch, and clear control signals, respectively. Figure 24 shows a single exposure pulse taken at station 5-5. All of the signals were obtained by monitoring the appropriate lines on the 100-pair cable. They all show a minimum voltage of -2.00 V relative to ttl ground. On the camera side of the camera power supply boxes, this minimum would be close to 0.0 V relative to ttl ground. The exposure pulse shown in Figure 24 is approximately 2 msec and is programmable both in duration and number. That is, longer exposures can be obtained by either increasing the duration of the pulse, which increases the length of time the displays are turned on, or by increasing the number of exposure pulses sent out.

Figure 25 is a blank film image taken from a camera in the range that shows an example of typical annotation data impressed upon the film. It was obtained by using the system described in this report. This was obtained from the pit camera in group 5, station 4. Exposure time for this was approximately 1 msec.

5. DISCUSSION

The camera annotation system has been in operation since January 1987 and has performed well. The system has shown that it is vulnerable to lightning storms and electrical disturbances. A particularly severe storm just after the initial operation caused some damage to some of the circuits in the cameras, especially near the end of the range at group 5. The 100-pair cable is especially vulnerable. Any unshielded portion tends to act like an antenna during electrical storms. The shield on this cable has been grounded at all entrances and exits of the various buildings to which it is available. In addition, surge protection devices have been used with all of the instrumentation associated with the camera system in order to minimize damage. These measures have helped considerably, but additional work is needed. Telephone companies use voltage protection devices that can be installed on the 100-pair cable system to protect the system from transients. Also, insuring that there is a good ground for the AC power system in the range will be beneficial.

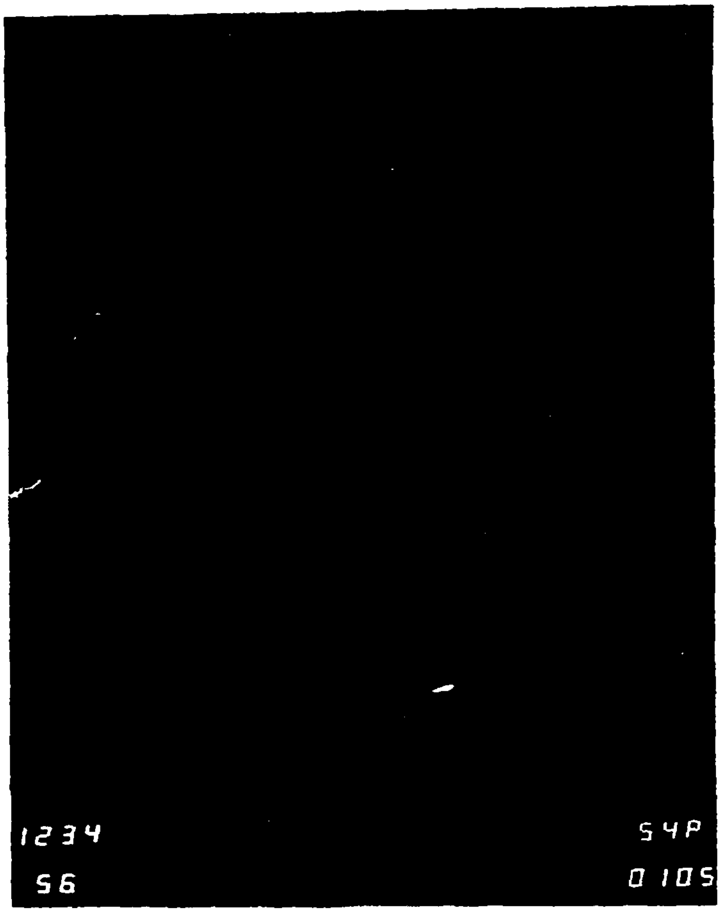


Figure 25. Blank film image with typical annotation data displayed (1-msec exposure).

The original circuit boards for the cameras were constructed using wire-wrap techniques. Since the installation of the annotation system, a supply of printed circuit boards for the cameras have been fabricated by a commercial vendor. These boards are shown in Figure 26 and will gradually be used to replace the wire-wrapped boards installed in the range, providing increased reliability.

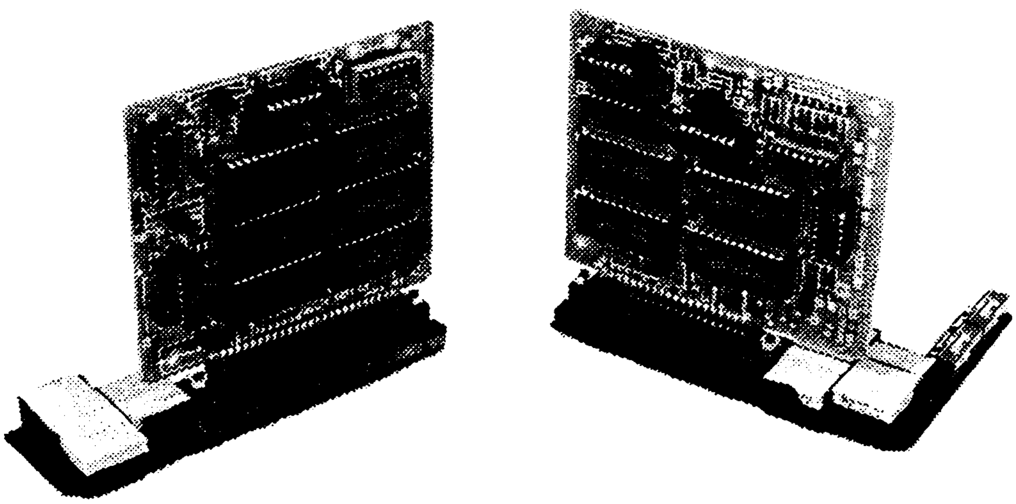


Figure 26. Photograph of final camera circuit boards utilizing printed circuit board techniques.

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